# GAP ANALYSIS OF INDIAN FOX CONSERVATION USING ECOLOGICAL NICHE MODELLING

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We used ecological niche modelling to predict the geographic distribution of the Indian Fox, a canid endemic to the Indian subcontinent. This little known canid, while not yet endangered, is threatened due to rapid habitat loss and poaching throughout its range. We analysed 58 known occurrence locations from survey data collected from three states in peninsular India using the software Desktop GARP. We created an ecological niche model for India using vegetation and topographic data and further refined it by including 18 additional bioclimatic data sets. Based on the ecological niche modelling results, a gap analysis of protection offered to potential Fox habitat in two states of southern India was conducted by overlaying existing protected area boundaries on the refined distribution and calculating the extent of protection. Our analysis showed that the Indian Fox habitat consists primarily of low elevation semi-arid grassland, scrub and thorn forests, which rank among the most vulnerable in India owing to conversion to agriculture, industry and urban areas. The gap analysis showed that a little over 1% of predicted Fox distribution is covered by the protected area network. The under representation of these habitats is deleterious not only to the Indian Fox but also to a range of other species, such as the endangered Great Indian Bustard, Indian Grey Wolf and Blackbuck.

**Key words**: Indian Fox, *Vulpes bengalensis*, ecological niche modelling, gap analysis, distribution, protected areas

## INTRODUCTION

The Indian Fox *Vulpes bengalensis*, a canid endemic to the Indian subcontinent, is widespread, ranging from the foothills of the Himalaya in the north to the southern tip of the Indian peninsula, and from Sindh Province of Pakistan east to Bangladesh (Johnsingh and Jhala 2004; Gompper and Vanak 2006). Even though this species is believed to be common (Johnsingh and Jhala 2004), little is known about its ecology or the details of its geographic distribution, or population status. The IUCN Canid Specialist Group classes this species as 'Least Concern,' (Johnsingh and Jhala 2004); it is listed under Schedule II of the Indian Wildlife (Protection) Act,1972 (as amended up to 2002), which prohibits hunting of this species (Anonymous 2002). Despite this protection, Indian Fox populations are declining owing to habitat loss from conversion to intensive agriculture, industry and development projects (Johnsingh and Jhala 2004).

The Indian Fox is found in semi-arid, flat or undulating terrain in biogeographic zones 3, 4 and 6 of India (Rodgers *et al.* 2000), which are typically drier biomes characterised by low rainfall, scrub, thorn, or dry deciduous forests or short grasslands (Manakadan and Rahmani 2000; Rodgers *et al.* 2000; Vanak 2005). Indian Foxes avoid dense forest, steep terrain, tall grasslands and true desert (Prater 1980; Johnsingh and Jhala 2004). Recent surveys indicate that though the species is widespread, it is not common through most of its range and is encountered at highest frequencies in protected semi-arid short grasslands and dry scrub areas (Vanak 2003, 2005; Vanak and Gompper 2007). Although these habitats rank among the most endangered in India (Rahmani 1989) and are subject to constant human encroachment, they are rarely the focus of conservation attention. Moreover, these habitats have been categorised as wastelands by various land management agencies and are subject to intense pressure to be transformed into agricultural and pastoral landscapes (http://dolr.nic.in/wasteland.htm accessed on January 28, 2008).

In the southern Indian states, Indian Fox habitats are decreasing, and the continued survival of the species is seriously threatened (Johnsingh and Jhala 2004). Despite a reported presence in some protected areas (PAs), most populations of this species remain outside the PA network (Vanak 2005). In the absence of systematic proactive efforts for its conservation, this species might suffer a substantial reduction in potential habitat, affecting its future survival. We thus developed a gap analysis of the protection currently afforded to Fox distribution areas in the southern Indian states of Karnataka and Andhra Pradesh.

Gap analysis is a proactive approach to planning timely action for species conservation that focuses on evaluating the degree to which native species are represented in PAs. Species not adequately represented in the existing PA network constitute 'gaps' in the conservation program. Gap analysis is intended to prevent additional species from becoming threatened or endangered, and in this sense is proactive, rather than reactive (Scott *et al.* 1993; Flather *et al.* 1997; Davis *et al.* 1998).

Mapping the distribution of a species exhaustively through on-ground surveys would be prohibitively expensive and time-consuming, if not simply impossible. The alternative used here is that occurrence data available from regions sampled in detail can be used to reconstruct the species' overall distributions using Ecological Niche Modelling (ENM) (Peterson and Kluza 2003; Peterson 2005). The ecological niche of a species can be defined as the set of ecological conditions within which it is able to maintain populations without immigration (Grinnell 1917; Holt and Gaines 1992). Several approaches have been used to approximate species' ecological niches (Austin *et al.* 1990; Walker and Cocks 1991; Scott *et al.* 1996; Scott *et al.* 2002); of these, one that has seen considerable testing is the Genetic Algorithm for Rule-set Prediction (GARP), which includes several inferential approaches in an iterative, evolutionary computing environment (Stockwell and Peters 1999). All modelling in this study was carried out on a desktop implementation of the GARP algorithm (Stockwell and Noble 1992; http://www.lifemapper.org/desktopgarp).

## MATERIAL AND METHODS

Ecological Niche Modelling (ENM) has been used in numerous applications and subjected to various tests, based on diverse analytical approaches (Miller 1994; Csuti 1996; Tucker *et al.* 1997; Gottfried *et al.* 1999; Manel *et al.* 1999a,b). The particular approach to modelling species' ecological niches and predicting geographic distributions used here (summarised below) is described in detail elsewhere (Stockwell and Peters 1999; Peterson *et al.* 2002). Previous tests of the predictive power of this modelling technique for diverse phenomena in various regions have been recorded elsewhere (Peterson 2001; Peterson *et al.* 1999; Peterson *et al.* 2002; Peterson and Vieglais 2001; Anderson *et al.* 2002, 2003; Stockwell and Peterson 2002).

GARP works in an iterative process of rule selection, evaluation, testing and incorporation or rejection: first, a method is chosen from a set of possibilities (e.g. logistic regression, bioclimatic rules), and is then applied to the training data, and a rule is developed; rules may evolve by a number of means (e.g. truncation, point changes, crossing-over among rules) to maximise predictability. The predictive accuracy is then evaluated based on 1,250 points resampled with replacement from the intrinsic testing data and 1,250 points sampled randomly from the study region as a whole to represent pseudo-absences. GARP is designed to work based on presence-only data; missing information is included in the modelling via sampling of pseudo-absence points from the set of pixels where the species has not been detected (Stockwell and Peters 1999). The change in predictive accuracy from one iteration to the next is used to evaluate whether a particular rule should be incorporated into the model, and the algorithm runs either 1,000 iterations or until convergence.

We used 58 unique point occurrences of the Indian Fox sampled from the states of Karnataka, Andhra Pradesh and Maharashtra, in 2003 and 2005 (Vanak 2003, 2005) (Fig. 1) for analysis. We used 'monthly' composites of the maximum Normalised Difference Vegetation Index (NDVI) images from the Advanced Very High Resolution Radiometer (AVHRR) satellite (Eidenshink and Faundeen 1994) for 2003, as well as elevation, slope, aspect and Compound Topographic Index (CTI) from the Hydro-1K data set (USGS 2001) and a global landcover coverage (Hansen *et al.* 1998, 2000). All environmental datasets were resampled to pixels of about 1 km × 1 km for analysis.

**Table 1**: Bioclimatic variables used for refining the distribution of the Indian Fox in the two southern states

| Sr. No. | Predictor Variables | Source |
|---|---|---|
| 1. | Mean monthly precipitation | WorldClim |
| 2. | Mean monthly temperature | WorldClim |
| 3. | Maximum monthly temperature | WorldClim |
| 4. | Minimum monthly temperature | WorldClim |
| 5. | Annual mean temperature | WorldClim |
| 6. | Mean diurnal range (mean of monthly max temp-min temp) | WorldClim |
| 7. | Isothermality (Feb precipitation / July precipitation) * 100 | WorldClim |
| 8. | Temperature seasonality (standard deviation *100) | WorldClim |
| 9. | Max temperature of warmest month | WorldClim |
| 10. | Min temperature of coldest month | WorldClim |
| 11. | Temperature annual range | WorldClim |
| 12. | Mean temperature of wettest quarter | WorldClim |
| 13. | Mean temperature of driest quarter | WorldClim |
| 14. | Mean temperature of warmest quarter | WorldClim |
| 15. | Mean temperature of coldest quarter | WorldClim |
| 16. | Annual precipitation | WorldClim |
| 17. | Precipitation of wettest month | WorldClim |
| 18. | Precipitation of driest month | WorldClim |
| 19. | Precipitation seasonality (coefficient of variation) | WorldClim |
| 20. | Precipitation of wettest quarter | WorldClim |
| 21. | Precipitation of driest quarter | WorldClim |
| 22. | Precipitation of warmest quarter | WorldClim |
| 23. | Precipitation of coldest quarter | WorldClim |

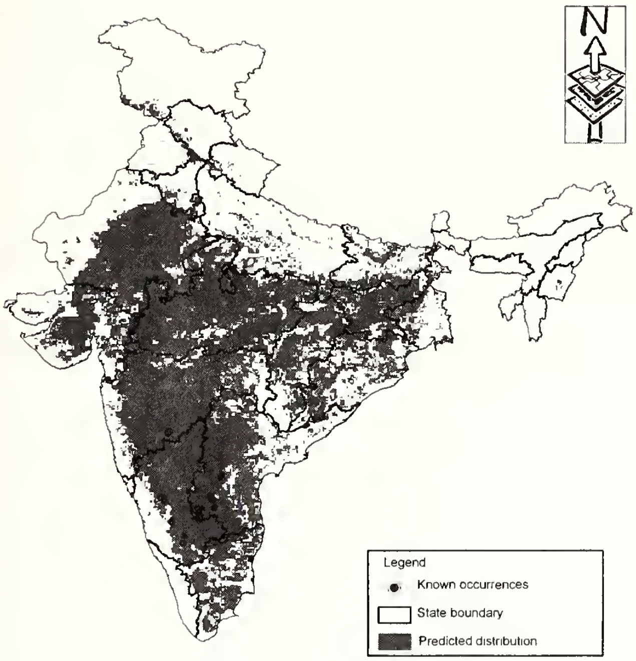


Fig. 1: Predicted distribution of Indian Fox *Vulpes bengalensis* in India based on NDVI and topographic variables
Note: The Model over-predicts distribution in some areas, such as north east India and Kashmir, where the species is not reported to occur

An arbitrary set of 100 model runs was developed for each analysis. In general, 25% (*c*. 14 points) of available occurrences were used for rule development (training data) and 25% (*c*. 14 points) for rule selection and refinement (intrinsic testing data), and the remaining 50% (*c*. 29 points) point locations were set aside for an independent test and filter of best quality models (extrinsic testing data). To choose the best models from among the 100 replicates, we filtered models on the basis of omission and commission error estimates, following recent recommendations (Anderson *et al.* 2003). First, 20 models with 0% omission errors were chosen, and of these 10 models within the central 50% of the commission values were selected as the best models.

**Table 2**: Predicted distribution of Indian Fox *Vulpes bengalensis* across landcover types in India

| Landcover type | Location equivalent | Landcover types within Fox distributional range (%) | Fox distributional range across each land cover type % |
|---|---|---|---|
| Water | Water | 0.2 | 2 |
| Woodland | Deciduous forest | 0.3 | 1 |
| Wooded grassland | Open scrub forest | 50.0 | 33 |
| Closed shrubland | Tropical thorn Forest | 23.6 | 62 |
| Open shrubland / grassland | Grassland | 23.7 | 29 |
| Cropland | Cropland | 2.1 | 3 |
| Bare-ground | Bare-ground | 0.2 | 1 |

To provide an independent validation of model performance, we randomly created four independent replicates of 40 point locations each from the original data set (n= 58). The remaining 18 points of each of these replicates were set aside for an independent test of the predictive accuracy for each replicate. Coincidence between independent testing points and model predictions for each replicate was used as a measure of model predictive ability. Binomial tests were used to compare the observed predictive success with that expected under random (null) models of no association between predictions and test points. The test results are in the form of a 'ramp' of model agreement from 0 (all models predict absence of 18 validation points) to 10 (all models predict presence of 18 validation points). Therefore, for each replicate, we calculated binomial probabilities at each of the 10 predictive levels (Anderson *et al.* 2003).

To characterise modelled distributions further, based on the existing knowledge of the species' habitat preferences, we overlaid the predicted Fox distribution on a global landcover data set (Hansen *et al.* 1998, 2000) for all of mainland India and calculated proportions of landcover types within the predicted distribution.

Since the potential distribution of the Indian Fox is limited in southern India and is decreasing, given growing urbanisation, change in land use patterns and human-induced disturbance (Johnsingh and Jhala 2004), we developed a gap analysis for the species with respect to the PA network within the states of Andhra Pradesh and Karnataka. We obtained PA boundaries for the two states and updated/corrected them using topographic maps. We repeated the modelling process by restricting ourselves only to the geographic limits of Karnataka and Andhra Pradesh to limit overprediction. We additionally incorporated 19 'bioclimatic' variables (Hijmans *et al.* 2004) in the analysis to improve the algorithm's resolving power and to obtained a refined estimate of the Fox distribution within the two states. We then overlaid existing PA boundaries to determine gaps in the protection of Indian Fox habitat. The reason we have done this for only these two states is that this is where the majority of the data comes from, and this allows us to better represent Fox distribution within a smaller geographic area. We believe the coarser analysis at a larger scale allows us to delimit the broader distribution of the species at a countrywide level, while the refined analysis allows us to overcome the inherent over-prediction of GARP distribution for gap analysis at the state level.

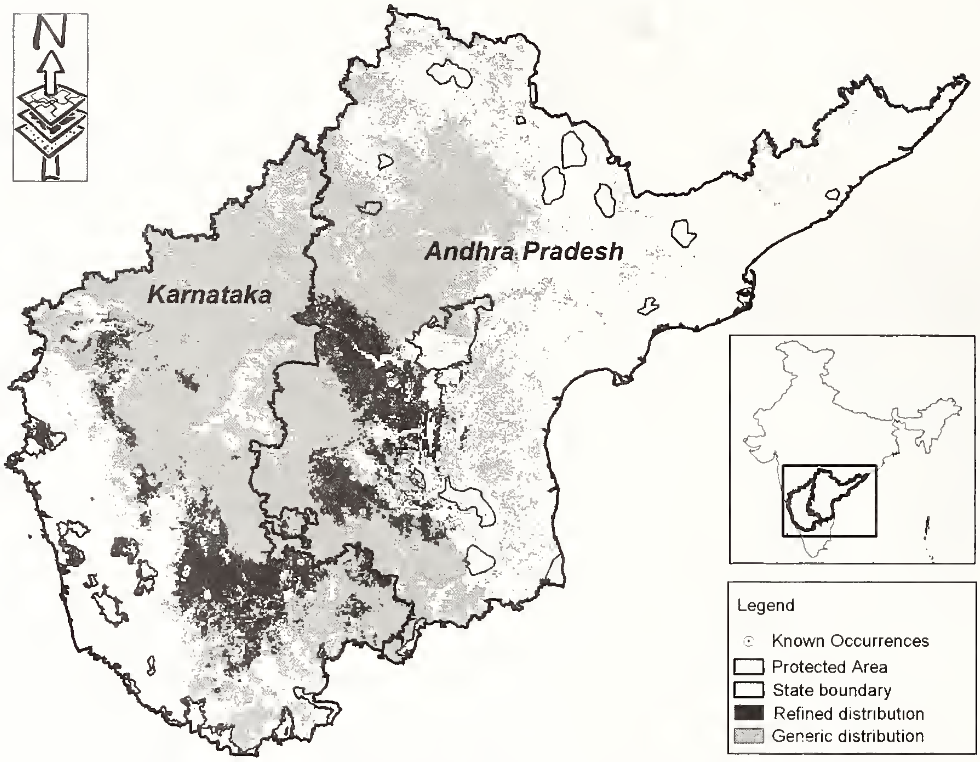


Fig. 2: Predicted distribution of Indian Fox *Vulpes bengalensis* in India based on NDVI and topographic variables

## RESULTS

We used model stacking to combine the results of the 10 best models for predicting the distribution of the Indian Fox. Independent validation of the predictive success of these models ranged from 11 to 18 correctly predicted occurrences out of the 18 testing points for each of the four replicates. Binomial probabilities at each of the 10 predictive levels in all cases (4 replicate tests x 10 predictive levels each) were significantly better than random (binomial tests, all $P << 0.05$). This success in predicting independent tests of occurrence data gave confidence in the model accuracy; as a result, we used all available points to develop final models (Fig. 1).

Further exploration of these final models illustrated the species' potential distribution in ecological dimensions. The Indian Fox occupies an elevation range of 100-900 m with low rainfall (500-1,000 mm) and moderate annual mean temperatures (25-30 °C). Peak NDVI values of the post-monsoon season (0.5-0.8) correspond closely to areas holding wooded grasslands, scrub and thorn forest systems. Cross-tabulating the predicted distribution with landcover data showed that 'open scrub forest' (50%) and 'grassland and tropical thorn forest' (47%) were the dominant representative landcover types within the species' distributional area (Table 2). Focusing within Andhra Pradesh and Karnataka and adding in the bioclimatic variables, the predicted distribution of the species was further refined to 4,70,951 sq. km (9%) of the total area of the states (Table 3, Fig. 2).

Overlaying the protected area network of the two states on the refined distribution map revealed that only seven PAs

**Table 3**: Area statistics of Indian Fox *Vulpes bengalensis* distribution in the states of Karnataka and Andhra Pradesh, India

| | Area (sq. km) | % of refined distribution | % of generic distribution | % of state geographic area |
|---|---|---|---|---|
| Karnataka (Geographic area – 1,92,493 sq. km) | | | | |
| Total generic distribution | 1,11,403 | | | 58 |
| Total refined distribution | 21,324 | | 19 | 11 |
| Total area (2 PAs) protected | 92.13 | 0.43 | 0.08 | 0.05 |
| Andhra Pradesh (Geographic area – 2,78,458 sq. km) | | | | |
| Total generic distribution | 1,04,270 | | | 37 |
| Total refined distribution | 21,833 | | 21 | 8 |
| Total area (5 PAs) protected | 495.51 | 2.27 | 0.48 | 0.18 |
| Combined total area protected for both states | 587.64 | 1.36 | 0.27 | 0.12 |

coincided with some part of the predicted range, protecting approximately 588 sq. km (*c.* 1%) of the species' potential distribution.

## DISCUSSION

The predicted range of the Indian Fox developed here agrees well with current knowledge of the species' distribution (Johnsingh and Jhala 2004). It excludes regions such as the Himalaya, the deserts of Rajasthan and the hill ranges of the Western and Eastern Ghats, from where the species has never been reported (Gompper and Vanak 2006) (Fig. 1). Despite the geographically limited sampling (limited areas in three states from peninsular India), the model performed well in capturing the species' ecological niche, as well as its geographic distribution, across a much broader region. Studies elsewhere have demonstrated a similar predictive performance of the GARP algorithm based on small numbers of training locations (Peterson 2001; Anderson *et al.* 2003; Peterson and Kluza 2003).

Our original models (NDVI and topography) predicted about 46% area of Karnataka and Andhra Pradesh as suitable (Table 3) while the analysis using an additional 19 variables permitted us to refine distributional estimates for this species, reducing it to 20% of the total extent of the states as the potentially suitable range. This analysis confirmed that low elevation grasslands, open scrub forest and tropical thorn forest constitute the bulk of the distribution of this species. These habitats also rank among the least represented in the Indian PA network (Rodgers *et al.* 2000). A clear demonstration of this under-representation is that only a little over 1% of the species' distribution potential in the two states is within the PA system.

It is therefore clear that key habitats for the Indian Fox are inadequately represented in the PA network of the states of Karnataka and Andhra Pradesh. A greater representation of dry-land biomes in the PA network would be positive, not only for the Indian Fox but also for other obligate dry grassland species such as the endangered Indian Bustard *Ardeotis nigriceps*, Indian Grey Wolf *Canis lupus pallipes*, and Blackbuck *Antilope cervicapra*. We suggest that this kind of predictive distributional modelling be used by conservation planners to identify crucial habitats for the protection of these endangered species.

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